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National Report for Canada

OCEANOGRAPHY IN CANADA

1957–60

for
INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS
INTERNATIONAL ASSOCIATION OF PHYSICAL OCEANOGRAPHY
TWELFTH GENERAL ASSEMBLY
HELSINKI, FINLAND, 1960

compiled by
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by

H. B. HACHEY
Chief Oceanographer
Fisheries Research Board of Canada

INTRODUCTION:

The Canadian Committee on Oceanography, as of December, 1959, is the re-organized Canadian Joint Committee on Oceanography which came into existence on April 1, 1946. Since 1946 oceanography in Canada has been co-ordinated under such a Committee which has been representative of all government agencies actively interested in the problems of the sea.

In the recent re-organization, the interests of the Committee have been broadened and its functions are now to:

(a) Co-ordinate the oceanographic activities of all Canadian Government agencies.

(b) Act, as designated by the National Research Council (NRC), as the National Committee for the Scientific Committee on Oceanographic Research (SCOR).

(c) Act, as designated by the National Research Council, as the Section on Oceanography of the NRC Associate Committee on Geodesy and Geophysics.

The Committee is comprised of representatives of the following Government Agencies:

The Royal Canadian Navy
The Fisheries Research Board
The Department of Mines and Technical Surveys
The Defence Research Board
The National Research Council
The Meteorological Branch, Department of Transport
The Marine Services, Department of Transport.

In addition there are representatives of academic interests in oceanography as nominated by the National Research Council.

Each of the co-operating organizations is either actively engaged in oceanographic investigations or contributes in ships, laboratory facilities, personnel, or funds towards the overall Canadian program. The total effort is co-ordinated through the Committee.

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There is an Institute of Oceanography at the University of British Columbia, Vancouver, B.C., under the directorship of Dr. G. L. Pickard, and an Institute of Oceanography at Dalhousie University, Halifax, N.S., under the directorship of Dr. F. R. Hayes. A Geophysical Research Group under the chairmanship of Dr. G. B. Langford at the University of Toronto, Toronto, Ont., is applying oceanographic methods to studies of our great inland seas. All three organizations are supported in part by funds from the National Research Council. The Departments of Zoology and Physics at McGill University, Montreal, P.Q., have research interests in marine biology and the physics of sea ice respectively. Problems in marine biology are also furthered by the Fisheries Institute of the University of British Columbia at Vancouver, B.C., the Regional Laboratory of the National Research Council at Halifax, N.S., and the School of Fisheries at Ste. Anne de la Pocatière, P.Q. The Department of Geology at Carleton University in Ottawa, Ont., and at the University of Montreal in Montreal, P.Q., are developing interests in phases of submarine geology. The Pacific Naval Laboratory at Esquimalt, B.C., and the Naval Research Establishment at Dartmouth, N.S., under the Defence Research Board conduct oceanographic research and surveys in support of military requirements.

The Fisheries Research Board, which serves as the scientific arm of the Federal Department of Fisheries, has been actively engaged in all phases of oceanography since 1910, with considerable impetus being given to the subject following the Canadian Fisheries Expedition of 1914–15 under Dr. Johan Hjort. Present activities are furthered by the Atlantic Oceanographic Group located at Halifax, N.S., the Pacific Oceanographic Group at Nanaimo, B.C., the Arctic Unit at Montreal, P.Q., and the Biological Stations at St. John's, Nfld., St. Andrews, N.B., and Nanaimo, B.C.

The Canadian Hydrographic Service of the Department of Mines and Technical Surveys has, from the time of Dr. Bell Dawson, pioneered in the study of tides and currents in areas of Canadian interest. Within the past two years, the Department of Mines and Technical Surveys has entered the field of oceanography on a more substantial scale. To meet requirements for greater attention to Arctic areas of national concern, a Polar Continental Shelf Project has been set up under the expanding plans. The Department also has under way the development of the Bedford Institute of Oceanography in Dartmouth, N.S., which is to be completed in five years. This Institute will house a staff of 300 oceanographers, hydrographers, submarine geologists, and other scientific personnel plus a supporting staff. The operating fleet will consist of ten oceanographic vessels. A multi-million-dollar ship building program is under way to provide the fleet of oceanographic vessels. The first of these, the $7,000,000 C.G.S.*Hudson,* is expected to be commissioned in 1961. Specifically, the new Institute will turn an oceanographic research spotlight on Canada's Atlantic and sub-Arctic waters. It will also permit expansion of hydrographic programs. The regional offices of the Geological Survey will be located in the Institute. It will also house the staff of the Polar Continental Shelf Project as well as the Atlantic Oceanographic Group of the Fisheries Research Board. The whole project will mean the building up, near

Dartmouth, of a strong center of marine sciences. It includes close co-operation with the Fisheries Research Board, with the Institute of Oceanography at Dalhousie University, with the Atlantic Regional Laboratory of the National Research Council, and with the Naval Research Establishment of the Defence Research Board. The overall development of the Bedford Institute will be in charge of Dr. W. M. Cameron.

The Province of Quebec maintains a Marine Biological Station at Grand River, P.Q., which gives attention to marine biological problems in the Gulf of St. Lawrence. Particular attention has been directed towards the general oceanography of the Bay of Chaleur.

At this stage of developments in oceanography in Canada, a most serious shortage of professional oceanographers exists, particularly in the physical and chemical disciplines. It is expected that as these developments in oceanography gradually come to fruition over the next five years, the required basic staffs can be built up with professional oceanographers who might be attracted from other areas, with repatriated Canadian professionals, and with the increasing number of graduates from our two Institutes of Oceanography.

The Canadian Oceanographic Problem

Canada has an enormous coast line, being bounded north, east, and west by three oceans, which are sources of food, means of transportation, factors in climate, and aids to defence.

As a source of food, the oceans present us with increasing economic and conservation problems as the world needs for protein brings greater pressure on fish stocks that at one time were considered inexhaustible. The major fish stocks off both the east and west coasts of Canada are being exploited as never before. The many international fisheries commissions now furthering research in these areas of Canadian concern indicate the importance that is attached to these ocean resources. While there are yet untapped resources of the sea, the economics of some of our present fisheries are of some concern to Canada at the present time. Some fisheries are not exploited to the full, and the efficiency of catching leaves much to be desired in others.

As a means of transportation, the oceans present a host of problems over a varied and extended coast line. Here the tides, currents, water characteristics and bottom configurations combine with wind, waves, swell, ice and icebergs to present a maze of challenging requirements for safe navigation, for the construction of wharves, harbours, causeways and bridges, and for defence. The recent developments of the large ore bodies in eastern Quebec, the industrialization of areas around the northern part of the Gulf of St. Lawrence, the operation of the St. Lawrence Deep Sea Waterway, and the requirements for sea-borne traffic in the Arctic have crystallized national requirements for a thorough study of ice in navigable waters. These studies which have recently expanded have already opened up further problems in the physics of ice, meteorology, and even in the design of ships for navigation through or under the ice.

As a factor in governing climate, the oceans are an important phase in the cycle of evaporation, cloud formation and precipitation. With

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oceans on three coasts, the interactions between sea and atmosphere are fundamental processes, and eventually must enter as parameters in long-range weather forecasts. While the waters on our northern coastline have ice cover for the greater part of the year, meteorologists have observed for example the very marked effect of the waters of Hudson Bay as conditions change from ice cover to open water and vice versa. However the problem is more than local, and involves the interactions of sea and atmosphere on a world-wide basis.

The oceans can still be considered an effective item of continental defence. They can also serve as an effective cover for under-sea craft which can remain submerged for long periods and serve as launching platforms for long-range missiles. Until recent years, the North American Continent, relatively untouched by modern wars, was looked upon as a bastion, well removed and protected from warring nations by the oceans on three coasts. In particular, the Arctic coast could be forgotten because of the difficulties of operation. Navigation under the Arctic ice by atomic-powered submarines has been shown to be feasible. This in itself has opened up a host of problems relating to defence. Methods of detecting the modern submarine are much more involved than heretofore, and a very technical knowledge of the ocean itself is required for efficient application of modern defence methods.

On the Atlantic coast the main water body of particular Canadian concern is contained within the area of confluence of two great ocean systems, the Gulf Stream and the Labrador Current. Thus the characteristics of the waters on our eastern sea coast are determined in the main by the mixing and layering of contributions from these two water masses, and modified in coastal areas by the contribution from land drainage systems. Of the land drainage systems, that of the St. Lawrence predominates, representing as it does the drainage from almost half a continent. The water areas within two hundred miles or more of our eastern coast support an enormous fishery, which has been known and exploited for centuries. The great contrasts in the waters of the Gulf Stream and the Labrador Current, the climatic variations in the mid-latitudes, the seasonal changes in the wind systems, the variety in the configuration of the sea floor and the coastline, the contrasting types of tide, the ice coverage, and drift of icebergs, establish a pattern of environments with a wide variety of parameters. To the oceanographer, whether interested in problems of food production, of transportation, of meteorology, or of defence, the area offers a particular challenge in many of its fundamental aspects.

In the northern latitudes of the northern hemisphere, the land masses offer considerable barriers to the exchange of waters as between the polar seas and the Atlantic and Pacific Oceans. The annual water balance of the Arctic Ocean has been calculated in which the inflow and outflow of waters through the Faeroe and Shetland Islands and the Danish and Bering Straits, and the continental run-off, have been taken into account. It has been indicated that there is a surplus of 31,400 cubic kilometres of inflowing waters which must be carried away annually from the Arctic Ocean through the numerous straits of the Canadian Archipelago. Hence on the Atlantic seaboard and in the eastern Canadian

Arctic, this outflow through Foxe Basin, Hudson Strait, Lancaster, Jones and Smith Sounds, and Kennedy Channel accelerate the Baffin Land and Labrador Currents which transport these Arctic waters with their ice and iceberg to the mid-latitudes of the Canadian Atlantic. In the western Canadian Arctic, west of Barrow Strait, the deeper waters are characteristic of those of the Polar Basin. The Canadian oceanographic problem in these far northern areas is concerned with the food resources of the sea for an Eskimo population, with navigation through ice-invested waters relating to supply missions, with development of natural resources, and with phases of continental defence.

The rugged Pacific Coast of Canada is indented with many deep inlets which present water bodies of various magnitudes with fjord-like characteristics. The oceanography of the immediate coastal seas is dominated by the outflow from the larger river systems and by the turbulent tidal currents in many straits and passages. The basic features of the ocean circulation in the North Pacific is the North Pacific Current, a part of the Kuroshio System. This North Pacific Current or west wind drift is the general eastward flow of comparatively warm water to the east of Longitude 160°E. To the north of the North Pacific Current and centred at about Latitude 50°N is found an entirely different sub-Arctic type of water which flows to the east and which is generally referred to as the Aleutian Current. As it nears the American coast one branch of this Aleutian Current turns south to form the California Current. Another branch turns north moving in a slow counter-clockwise gyral around the Gulf of Alaska. An extension from the head of the Gulf of Alaska which turns westward and then southwest, all the while undergoing acceleration, has been named the Alaskan Stream. Recent estimates of the volume transport of the gyral give values of 18 cubic kilometres per day, with surface velocities of 2 to 5 miles per day. It appears that the area of division of the west wind drift shifts from time to time to the south, the volume transport of the Alaska Gyral increases, and water warmer than usual moves northward past the Canadian coast. Many features of the oceanography of the North Pacific are related to the wind system which is variable in time and space. The dominant winds change with the season; the northwesterly winds favour upwelling on the coast, while southerly winds favour transport of surface waters towards the coast.

The Northeast Pacific Ocean is a prolific feeding ground for the various species of salmon that provide the valuable salmon fisheries on the Pacific Coast. The enrichment of the waters is provided through physical processes that bring the nutrients from the greater depths to levels where they enter into the cycle of production. These processes are enhanced in part by wind action. In this Northeast Pacific area in recent years, the successful application of oceanography to a major fisheries problem on an international scale has been ably demonstrated. The distribution of the salmon throughout this area, and the dependence of the North American coastal fishery on the well-being of the salmon in the sea have been demonstrated. This has emphasized the necessity of international control of fishing on the high seas.

Transportation problems on the Pacific Coast of Canada are confined to the immediate coastal areas, while the defence problems are those common to all coasts.

There are a number of problems of deep ocean circulation that are of fundamental importance to world well-being. The number of years during which a particle of water has been removed from contact with the atmosphere can be determined today for example by measuring the relative concentrations of carbon-14 and carbon-12 in a sample of sea water. The disposal of radioactive wastes, whether by burying on land or by dumping in the sea, constitutes a real problem which is being given attention by international bodies. The disposal of such wastes has been carried out today without too much consideration to the possible end result. Eventually, whether buried on land or dumped in the sea, these materials will be carried about in the great circulation systems of the oceans. The time factor is of course the major concern.

The sun provides the energy to move both sea water and air between the "furnace" of the tropics to the "condensers" of the polar regions. The circulation of the working fluids is demonstrated by the wind systems and the currents of the sea. In the circulation system of the oceans, the equatorial currents and the other major currents, such as the Gulf Stream and Kuroshio, are well known. The vertical circulations and the return currents at the abysmal depths are however at present only matters of very rough estimates. The rate of transport of deep water between high and low latitudes and the rate of exchange of heat with surface water in high latitudes determine the total gain or loss of heat by the oceans. The time element may be a year, a decade or centuries. Hence a very small temperature change in the deep waters would be indicative of a departure from a radiation balance between the sun and the earth. This radiation balance is a prime parameter in the problem of long-range weather forecasting.

The practical end result of productivity in the sea is measured by man in the amount of food he actually takes from it. In this sense we can look upon the areas of Canadian fisheries as most productive. At the same time, we are by no means harvesting the total protein crop available to us. We are aware, however, that there are fluctuations in the abundance of some of the more prized species of fish and animal life, and we are reaching the point in some areas and in some species that man takes all that can be readily caught. We can, therefore, expect that in some species there will be greater fluctuations in abundance, unless the particular fishery is brought under proper management. It is fundamental that knowledge of the factors affecting the production of stocks is necessary to proper management. Fundamentally, productivity has a much broader meaning. The food cycle in the sea involves the process of photosynthesis wherein plants grow under the action of sunlight. The great bulk of this primary production exists in the seas in the form of phytoplankton, and it is estimated that the amount produced per year exceeds the production of living matter on land. In the complete food chain from the minute plants to the full-grown fish and animal life there are many weak links or "limiting factors". The amount of sunlight available for plant production and growth varies with latitude, time of year, state of the sky and sea

surface, and qualities of the water. The necessary nutrient materials vary in quantity and availability. As all growth is a chemical process, temperature is a factor in the rate of production. The food chain is broken down at times by the ferocious grazing of living organisms on plant life or by one organism on another. For these reasons, the productivity is more accurately measured by the actual determination of the decrease of carbonate or the increase of dissolved oxygen in a sample of sea water where photosynthesis is taking place. The supply of nutrients, particularly those containing nitrogen and phosphorus, is renewed by the decomposition of dead plants and animals through the action of bacteria. The factors affecting the bacteria and other agencies of decay, particularly at the mud–water interface at the bottom of the sea, are not very well known.

As on land, if the end product is not harvested, it dies and returns to the cycle of the sea. A population explosion or an excessive schooling of fish may overgraze a portion of the sea, or may deplete the oxygen, and hasten its removal from the living chain. Another type of population explosion is involved in the phenomenon of the red tide, which proves toxic to higher forms of life in the sea. The destruction of the tile fish in the Gulf of Maine in the late nineteenth century, and the destruction of an estimated millions of tons of fish in the Indian Ocean in 1959 are examples of the effects of sharp changes in environment. That disease has killed off bodies of fish has been well demonstrated in the disasters that have affected Atlantic Coast oyster areas, and by observations over a period of years on Atlantic herring.

The geological history of the oceans is, to a large extent, recorded in the sediment of the deep ocean basins. The processes of sedimentation are associated, in part, with the deep ocean circulation, one phase of which may involve turbidity currents of considerable magnitude. During the present year, man has conquered the outer shell of "inner space" by means of the bathyscaphe. This new tool may now offer extraordinary facilities for penetrating the earth's crust to depths only dreamed of to date by geophysicists. We know that a great diversity characterizes the floor of the ocean basins and in the general plan we can distinguish between abysmal and shallow depths, shoals, ridges, and canyons. In detail, a knowledge of the ocean floors would offer insight into the building and erosion processes which we might consider at least in some areas as more accelerated than those on land. Mountain ranges there are under the surface of the sea mightier than those we know of on land. In the investigations of "inner space" the geophysicist has a particular interest in comparing his theories of mountain building as between the continents and the oceans.

General Oceanographic Activities 1957–60

During the period reported upon, Canada contributed to the oceanorgraphic projects of the International Geophysical year (IGY). The projects involved were Sea Level Recording, Deep Water Circulation, Polar Front Survey, Multiple Ship Surveys, Observations from Weatherships, and Ice Island Observations.

The study of tidal phenomena and mean sea level behaviour on our east, west and Arctic coasts was carried out by the Canadian Hydrographic Service. In the first two regions there existed a reasonably good network of permanent tide gauging stations from which basic data have been obtained over a long period of years. A concerted effort was made to rectify a deficiency of information in the Arctic and sub-Arctic regions. Two permanent stations were established, one at Resolute Bay and another at Brevoort Harbour. In addition, a series of temporary stations were established along the coasts of Baffin Island, Hudson and James Bays. The tidal station at Brevoort has since been closed and a new one opened up at Tuktoyaktuk on the Beaufort Sea. Preliminary work has been carried out at several other sites in the Arctic under a program for a network of permanent tide gauges in northern Canada. A regular series of oceanographic stations for monitoring the densities of the water column were maintained on the east and west coasts throughout the IGY period by the Fisheries Research Board and the Defence Research Board.

Contributing to the study of deep ocean water circulation, as programmed on an ocean-wide basis for IGY, an extensive survey was made of the waters of the western North Atlantic between Bermuda and Davis Strait. The sea program included observations of temperatures and salinities, and chemical analysis for dissolved oxygen, phosphate, silicate and nitrite. Various biological collections were also made. While bottom water conditions were fairly uniform in the Atlantic Ocean basins with salinities and temperatures holding to 34.9‰ and 2.5°C, surface salinities and temperatures ranged from 36.5‰ and 27.0°C off Bermuda to 31.5‰ and 4.0°C in Baffin Bay.

Extension of seasonal cruises involved the Grand Banks and the area to the east of Newfoundland in March and October, 1958, and in February and August, 1959. Oceanographic conditions on the Scotian Shelf were monitored seasonally in 1958 and 1959. The Labrador Current was again sectioned from Baffin Island southward during the summer of 1959. All of this contributed to the Polar Front Survey in the western North Atlantic which was co-ordinated through ICES and ICNAF.

An International Passamaquoddy Fisheries Board was set up in 1957 to investigate the effect of power dams in a proposed project for developing tidal power in the Passamaquoddy Region. The investigation under this Board consisted, in part, of an intensive effort over a three-year period to determine the tidal and non-tidal currents, the distribution of water properties and the controlling or relating factors. The study encompassed the Passamaquoddy Bay region and the contiguous regions of the Bay of Fundy and the Gulf of Maine. The field programs, which involved current measurements from an anchored ship, drift bottle releases, temperature and salinity observations, transport measurements by electromagnetic methods, and drift pole tracking have been completed. The analysis and interpretation of the data have been directed to estimating the changes that may occur if power dams are installed. The Fisheries Research Board and the Canadian Hydrographic Service co-operated in various phases of this project.

On the Atlantic Coast, the tendency is now toward lowered water temperatures. This tendency was particularly intensified during the later

months of 1958 and the winter months of 1959. That this trend has prevailed in more northerly areas in recent years is shown by a comparison of water conditions in the Labrador Sea and Davis Strait in the period 1920–35 with those of the period 1950–55. The decrease in water temperatures is of the order of one to four degrees centigrade in the surface waters, and one degree or less at 100 and 200 metres. In contrast, the bordering Atlantic waters were slightly warmer for the period 1950–55. Lowered salinities seem to be associated with lowered temperatures.

On the Pacific coast, contributing to both the Polar Front surveys and the Multiple Ship surveys, extensive coverage of the eastern North Pacific was made between July 1958 and December 1958. Additional coverage was made in 1959. These activities included quasi-synoptic surveys of the Aleutian area, the mid-ocean and coastal regions and the series observations at Ocean Weather Station "P" and along the coast. A continuing series of observations at Ocean Weather Station "P" was inaugurated, and in 1959 the section between the coast and the Station was occupied at approximately six-week intervals. Data are now on hand to define the predominant features of the water masses, the properties of the water, the structure and the currents in the upper 2000 metres of the eastern sub-Arctic Pacific. Attention has also been directed to progressive as well as seasonal changes in oceanographic conditions.

The recent studies on the Pacific coast in relation to the Northeast Pacific have shown that over the area generally precipitation exceeds evaporation. The resulting fresher surface water moves through and out of the region entraining sea water from below. A halocline separates an upper layer of comparatively uniform salinity from a more saline lower layer. In the lower layer, two primary sub-surface water masses, differing in temperature, may be identified. As these waters rise through the halocline to depths of less than 100 metres, they lose their identity. Through 1957 and 1958 there has been an intrusion of a warm water mass northward past the Canadian coast. This intrusion is readily described at depths of 200 metres near the coast, and at depths of 100 metres in the center of the Gulf of Alaska. It reached its maximum in August 1958, and has since undergone numerous fluctuations in strength.

Productivity studies of the waters of the North Pacific have shown them to be rich in nutrient material. Phosphates and silicates are always abundant but there is some evidence that nitrates may become a "limiting factor" as in near-shore waters. Primary productivity is generally controlled by the amount of light. A study of primary productivity has been carried out at Ocean Weather Station "P". This involved the determination of the standing crop of phytoplankton and the factors that affect it, such as insolation, light penetration, nutrient content, horizontal and vertical water movements, temperature and salinity structures, and the heat budget. The upwelling that is associated with a cyclonic water movement, as exemplified in the Alaska Gyral, encourages a high productivity in the open waters of the Gulf of Alaska. Seasonally, a high productivity would be expected in the Canadian coastal areas, when surface waters are moved offshore by the prevaling northwesterly winds. There is a

suggestion that waters of comparatively low dissolved oxygen content move shoreward at such times and may be a limiting factor to some living organisms on the shelf.

Theoretical studies have developed methods of computing the potential wind-driven transport in the ocean from the distribution of barometric pressure. The methods have been applied to North Pacific waters, and monthly assessment charts are being issued.

Throughout this period reported upon, the Canadian Hydrographic Service has been associated with a number of national developments requiring detailed investigations of tides and currents. Among these were the studies relating to tidal power development, causeway construction across Northumberland Strait, design of harbour facilities on the east coast, currents through the Gulf Islands and Smith Sound, and features of the Ripple Rock project on the west coast.

Oceanographic investigations in the Arctic were again carried out in 1957 by the Atlantic Oceanographic Group from H.M.C.S. *Labrador* in Hudson Strait and Frobisher Bay, Lancaster Sound, Bellot Strait, Wellington Channel, Baffin Bay and Davis Strait. The most intensive and detailed effort was made in Bellot Strait. There was a successful co-ordination of program in physical and chemical oceanography, marine biology, and marine geology. An extensive marine geological survey involved the taking of 30 cores and 126 grab samples. In 1959 a two-month detailed survey of currents and water properties was made over the inner half of Hudson Strait by the Department of Mines and Technical Surveys in the M.V. *Theta*. At six stations along a cross-section currents were recorded continuously at a depth of 30 metres for seven weeks, while at each station currents were observed at several other depths for periods up to 72 hours. General oceanographic observations were made at each of these stations and also at intermediate points. The outer half of Hudson Strait was given attention in September–October of the same year by a team of oceanographers, with the *Labrador* (now the C.G.S. *Labrador*), involving the Department of Mines and Technical Surveys, the Fisheries Research Board, and the Great Lakes Geophysical Research Group. During 1959 too, the Arctic Unit of the Fisheries Research Board made a very thorough coverage of the southeastern portion of Hudson Bay as well as James Bay. Of particular interest to the oceanography of the Canadian eastern Arctic is the recently published paper on the annual oceanographic cycle at Igloolik. An oceanographic station was occupied over a full year in a region of net flow of Arctic water from Fury and Hecla Strait. Water temperatures varied only by 3.55°C at all depths during the year and only by 0.07°C between November and May. Salinities varied between 1.68‰ and 32.59‰. Oxygen content, inorganic phosphate, and plankton varied greatly throughout the period.

The general oceanography of Hudson Strait is now fairly well known particularly after the intensive surveys of 1955, 1956 and 1959. Waters from Foxe Basin, Hudson Bay, and the Atlantic Ocean enter the strait, and each water of contrasting characteristics exerts its own specific influence on conditions in the strait. The deep water circulation is characterized by two opposing flows, one originating from Hudson Bay and Foxe Basin, and the other originating from the Atlantic Ocean.

The extent of Atlantic water intrusion into the strait is dependent, in part, on the volume of discharge from Hudson Bay. The surface circulation of the strait is dominated by what appears to be a steady outflow from Hudson Bay along the southern side of the strait. During July 1957, the peak net discharge from Hudson Bay eastwards was calculated at 0.3×10^6 cubic metres per second. Later in the season, the calculated discharge amounted to 0.2×10^6 cubic metres per second.

On Ice Island T-3, where oceanographic observations over a period of five months were made in association with the Cambridge Research Center of the USAF in 1958, the average drift of the island was of the order of two miles per day. Water temperatures recorded varied between 0.47°C and -1.71°C below the ice, while temperatures at depths of 2,000 metres varied but little during the period of observation (-0.1°C at 1,000 metres; -0.4°C at 2,000 metres). At 150 metres, the phosphate content was exceptionally high with maximum values throughout the summer at 3.0 microgram-atoms per litre. Oxygen concentrations were generally high.

Under the expanding program of the Department of Mines and Technical Surveys, a Polar Continental Shelf Project was set up in 1959. This project involves integrated investigations under various disciplines in the general area of the polar continental shelf and the Arctic Ocean within the Canadian Archipelago. The study of oceanic waters of Arctic Canada and the adjacent Arctic Ocean form a major part of the project. The long-range objective of the oceanographic studies is to obtain an understanding of the distribution, extent, composition, movement and history of the oceanic waters lying to the north of the mainland of Canada. The field work under this project was initiated in 1959. For technical reasons the area involved has been divided into blocks about 350 kilometres wide and extending out to sea a distance of 500 kilometres. A block based on Ellef Ringnes Island serves as the initial area of investigation. The work here in 1959 was of an exploratory nature and involved problems of position fixing and of operation under the prevailing conditions on the ice. The field program in 1960 will continue until early October. Disciplines involved are marine geology, seismology, marine biology, gravity, magnetism, sea-ice studies, hydrography, surveying and oceanography. In addition to three traverses running out to sea at intervals of 150 kilometres, sections are being occupied across the various straits and passages within working distance of the base.

Working Group on Ice in Navigable Waters

The Working Group on Ice in Navigable Waters was set up under the Joint Committee on Oceanography (now the Canadian Committee on Oceanography) to co-ordinate and encourage research in the field of ice in navigable waters. Particular attention has been given to the following activities:

(a) The development of techniques for forecasting ice growth, degeneration and movement,

(b) Studies of the physical properties of ice,

(c) Studies of the dynamics of the ice–air and ice–water interfaces,
(d) Climatological studies,
(e) The promotion of a standard terminology and codes for reporting ice.

Canadian studies of the physical properties of sea ice have been furthered largely by the Ice Research Project of McGill University and the Defence Research Board's Northern Laboratory at Fort Churchill. The Ice Research Project was set up in 1956. A field station at Shippegan, N.B., was operated during the winter for the years 1956–59, where the work consisted mainly of beam tests, ring tensile tests, and the relation of ultimate strengths to other variables. Crystal size seemed to be a more important independent variable than salinity. Further ring tensile and shear tests were carried out in the Northern Laboratory of the Defence Research Board at Churchill. In 1959, elastic properties of ice were studied in Barrow Strait, Young's modulus was related to salinity, and an empirical formula developed. The composition of salt water ice is being studied at McGill. Ice observing and reconnaissance is being carried out by the Meteorological Branch of the Department of Transport on the east coast, as well as in the Arctic, with a staff of fourteen trained and experienced ice observers. An additional ten observers will be undergoing training this year. The service is particularly valuable to winter and spring shipping in the Gulf of St. Lawrence and to the supply services in the Arctic. The Geographical Branch of the Department of Mines and Technical Surveys has completed in co-operation with DRB and the RCAF five consecutive years of ice reconnaissance in the Gulf of St. Lawrence, the results being intended chiefly for historical and climatic purposes.

During 1959, the ice forecasting services were taken over by the Meteorological Branch of the Department of Transport and the Ice Central is now located at Halifax, N.S., with expanded supporting staff and facilities. Forecasting activities cover the shipping channels below Quebec City, the Strait of Belle Isle, the shipping route to Churchill in Hudson Bay and the re-supply lines to weather station and DEW line sites. Five-day and three-day forecasts are issued by the Ice Central. These were supplemented in some areas of the Eastern Arctic by two-day forecasts and advisories.

The National Research Council has been giving attention to energy exchanges from snow, ice and water surfaces, and has been studying frazil ice formations in the St. Lawrence River. The Ice Atlas of the Canadian Arctic prepared under a Defence Research Board contract is now being printed. The new Pilot of Arctic Canada, Vol. 1, has recently been published by the Canadian Hydrographic Service. A section of this Pilot deals with Arctic ice. Volume 2 will be issued this year.

Institute of Oceanography—University of British Columbia

Graduate studies in oceanography are attracting a small but increasing number of Canadian students. The graduates have been readily absorbed into various departments of the government research activities. The Institute is receiving additional financial support from the National

Research Council in the form of annual grants. The additional funds have been used to increase the staff of the Institute and to provide adequate research equipment and facilities. Research activities include the study of the distribution of water properties in British Columbia inlets, theoretical studies of internal waves, various aspects of wave/shear current interactions, turbulent mixing in a fluid in the presence of a density gradient, and the distribution of algae and of zooplankton as indicators of water mass characteristics and movements. Recent additions to staff will introduce further disciplines to the research program.

Institute of Oceanography—Dalhousie University

Funds for the establishment of the Institute of Oceanography at Dalhousie University were made available by the National Research Council in 1959, and support will be continued on an annual basis. The research program includes studies on the dynamics of zooplankton production, the cycle of energy in the surface of the sea, marine bacteriology especially at the sediment–water interface, and the age of sediments. The disciplines of physics and geology will enter into the research program as staff appointments are completed. Courses at the graduate level in oceanography are being offered.

The Great Lakes Geophysical Research Group

Several years of preliminary geophysical research in Lakes Erie, Huron and Ontario, and in Georgian Bay were furthered by the Ontario Department of Lands and Forests. This was followed by the organization of the Great Lakes Geophysical Research Group under the University of Toronto to give greater attention, in an expanded program, to the geophysical problems of our great inland seas. The expanded program is furthered in part by a grant from the National Research Council and through the provision of a ship by the RCN. Assistance in operating the ship has been received from the Federal Department of Mines and Technical Surveys and from the National Research Council. Particular attention is being paid to physical limnology and studies of low-level atmospheric conditions over the lakes. Studies of bottom sediments, of waves, and of shore erosion processes form part of the program. Graduate training in hydrometeorology is offered as well as courses in other phases of geophysics.

The Royal Society of Canada and Oceanography

The activities of the Royal Society of Canada in the field of oceanography extend over a period of seventy years, as it was in part, through Section III, that the Tidal and Current Survey was established. Sixty years ago the activities of Section V resulted in the establishment of a Marine Biological Station. During the last several years the interest of the Society in the field of oceanography has been furthered by a Committee on Oceanography. The Committee is comprised of representatives of Section III, IV and V and through its activities has continued to further the development of oceanography on a national scale.

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